26. A 1975 kg car is parked at the top of a steep 42 m long hill inclined at an angle of 15°. If the car starts rolling down the hill, how fast will it be going when it reaches the bottom of the hill? (Neglect friction.)

27. Starting from rest, a cyclist coasts down the starting ramp at a professional biking track. If the ramp has the minimum legal dimensions (1.5 m high and 12 m long), find

(a) the acceleration of the cyclist, ignoring friction

(b) the acceleration of the cyclist if all sources of friction yield an effective coefficient of friction of $\mu = 0.11$

(c) the time taken to reach the bottom of the ramp, if friction acts as in (b)

28. A skier coasts down a 3.5° slope at constant speed. Find the coefficient of kinetic friction between the skis and the snow covering the slope.

QUICK LAB

The Slippery Slope

TARGET SKILLS

- **Performing and recording**
- **Analyzing and interpreting**

You can determine the coefficients of static and kinetic friction experimentally. Use a coin or small block of wood as the object and a textbook as a ramp. Find the mass of the object. Experiment to find the maximum angle of inclination possible before the object begins to slide down the ramp (θ_1). Then, use a slightly greater angle (θ_2), so that the object slides down the ramp. Make appropriate measurements of displacement and time, so that you can calculate the average acceleration. If the distance is too short to make accurate timings, use a longer ramp, such as a length of smooth wood or metal.

Analyze and Conclude

1. Calculate the gravitational force on the object (weight). Resolve the gravitational force into parallel and perpendicular components.

2. Draw a free-body diagram of the forces acting on the object and use it to find the magnitude of all forces acting on the object just before it started to slide (at angle θ_1). **Note:** If the object is not accelerating, no net force is acting on it, so every force must be balanced by an equal and opposite force.

3. Calculate the coefficient of static friction, μ_s, between the object and the ramp, using your answer to question 2.

4. Use the data you collected when the ramp was inclined at θ_2 to calculate the acceleration of the object. Find the net force necessary to cause this acceleration.

5. Use the net force and the parallel component of the object's weight to find the force of friction between the object and the ramp.

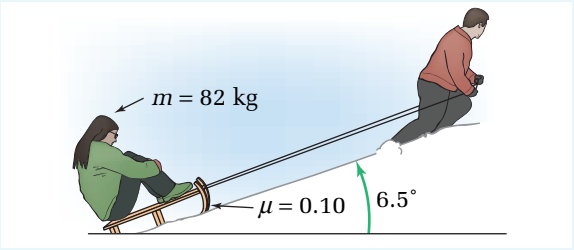
6. Calculate the coefficient of kinetic friction, μ_k, between the object and the ramp.

7. Compare μ_s and μ_k. Are they in the expected relationship to each other? How well do your experimental values agree with standard values for the materials that you used for your object and ramp? (Obtain coefficients of friction from reference materials.)

SAMPLE PROBLEM

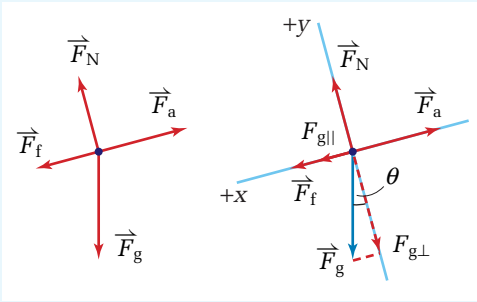
Pushing or Pulling an Object Up an Incline

You are pulling a sled and rider with combined mass of 82 kg up a 6.5° slope at a steady speed. If the coefficient of kinetic friction between the sled and snow is 0.10, what is the tension in the rope?



Conceptualize the Problem

- Sketch a *free-body diagram* of the forces acting on the sled. Beside it, sketch the *components of the forces* that are *parallel* and *perpendicular* to the slope.
- Since the sled is moving at a *constant velocity*, the *acceleration is zero*.
- The *parallel component* of the sled's weight and the *force of friction* are acting *down* the slope (*positive* direction).
- The *applied force* of the rope acts up the slope on the sled (*negative* direction).
- The *tension* in the rope is the magnitude of the *force* that the *rope exerts* on the sled.
- *Newton's second law* applies independently to the forces perpendicular and parallel to the slope.



Identify the Goal

The magnitude of the tension, $|\vec{F}_a|$, in the rope

Identify the Variables and Constants

Known	Implied	Unknown
$m = 82$ kg	$g = 9.81 \frac{m}{s^2}$	$\vec{F}_g$ $F_{g\|\|}$ $F_{g\perp}$
$\mu = 0.10$	$a_{\|\|} = 0 \frac{m}{s^2}$	$\vec{F}_N$ $\vec{F}_f$ $\vec{F}_a$
$\theta = 6.5°$		
v = constant		

Develop a Strategy

Apply Newton's second law to the forces perpendicular to the slope. Refer to the diagram to find all of the forces that are perpendicular to the slope. Solve for the normal force.

$$\vec{F} = m\vec{a}$$
$$F_N + F_{g\perp} = ma_\perp$$
$$F_N - mg\cos\theta = ma_\perp$$
$$F_N = mg\cos\theta + ma_\perp$$

Insert values and solve. Note that the acceleration perpendicular to the slope ($a_\perp$) is zero.

$$F_N = (82\text{ kg})\left(9.81\ \frac{m}{s^2}\right)\cos 6.5° + 0$$
$$F_N = 799.25\text{ N}$$

Apply Newton's second law to the forces parallel to the slope. Refer to the diagram to find all of the forces that are parallel to the slope. Solve for the force that the rope exerts on the sled.

$$\vec{F} = m\vec{a}$$
$$F_f + F_a + F_{g||} = ma_{||}$$
$$\mu F_N + F_a + mg\sin\theta = ma_{||}$$
$$F_a = ma_{||} - \mu F_N - mg\sin\theta$$

Insert values and solve.

$$F_a = (82\text{ kg})\left(0\ \frac{\text{m}}{\text{s}^2}\right) - (0.10)(799.25\text{ N}) - (82\text{ kg})\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)\sin 6.5^\circ$$

$$F_a = -79.925\text{ N} - 91.063\text{ N}$$

$$F_a = -170.988\text{ N}$$

$$|\vec{F}_a| \cong 1.7 \times 10^2\text{ N}$$

The tension force in the rope is about 1.7×10^2 N.

Validate the Solution

The tension is much less than the force of gravity on the sled, since most of the weight of the sled is being supported by the ground. The tension is also greater than the parallel component of the sled's weight, because the rope must balance both the force of friction and the component of the force of gravity parallel to the slope.

PRACTICE PROBLEMS

29. You flick a 5.5 g coin up a smooth board propped at an angle of 25° to the floor. If the initial velocity of the coin is 2.3 m/s up the board and the coefficient of kinetic friction between the coin and the board is 0.40, how far does the coin travel before stopping?

30. You are pushing a 53 kg crate at a constant velocity up a ramp onto a truck. The ramp makes an angle of 22° with the horizontal. If your applied force is 373 N, what is the coefficient of friction between the crate and the ramp?

1.4 Section Review

1. K/U Sketch a free-body diagram and an additional diagram showing the parallel and perpendicular components of gravitational force acting on an object on a ramp inclined at an angle of θ to the horizontal. State the equation used to calculate each force component.

2. K/U Which component of gravitational force affects each of the following?

(a) acceleration down a frictionless incline

(b) the force of friction acting on an object on a ramp

(c) the tension in a rope holding the object motionless

(d) the tension in a rope pulling the object up the ramp

3. C Why is it necessary to use two coefficients (kinetic and static) to describe the frictional forces between two surfaces? How do you decide which coefficient to use when solving a problem?

4. C Suppose you are pulling a heavy box up a ramp into a moving van. Why is it much harder to *start* the box moving than it is to *keep it moving*?